Energy Storage

THE BACKGROUND OF THE INVENTION AND PRIOR ART

The present invention relates generally to storage of electrical energy. More particularly the invention relates to an arrange-
5   ment according to the preamble of claim 1 and a vehicle according to claim 9. The invention also relates to a method of charging a number of electrical storage modules according to the preamble of claim 10, a computer program according to claim 15 and a computer readable medium according to claim
10 16.

Recent technology development has placed a strong demand for efficient electrical power sources. For instance, in today's vehicular industry it is particularly important that any onboard generated electrical energy can be stored as efficiently as
15 possible and constitute a reliable source of energy. Namely, the functionality of the modern vehicles is very dependent on electri-cally powered equipment. Moreover, hybrid vehicles and purely electrically propelled vehicles now begin to play an increasingly important role on the transportation market.

20 Therefore, highly efficient battery charging techniques are required. One example of an electrical charging system is described in the U.S. patent No. 6,215,277. Here, a control module selectively controls a charging current to one out of two batteries, which may have different output voltages. Thus, both
25 the batteries can be charged without a DC-to-DC converter being required.

U.S. patent No. 6,462,511 discloses a pseudo-parallel charging system for charging segmented batteries, wherein a current switching device routes a charging current from a charge source
30 to a selected battery segment while the remaining battery seg-ments are in a relaxation mode, i.e. do not receive any charge

current. Thereby, a cost-efficient solution for charging large battery packs is accomplished.

The U.S. patent No. 6,275,004 relates to an apparatus for balancing a battery module, wherein a plurality of batteries are connected in series to supply power to a vehicle. A generator voltage is here DC-to-DC converted and delivered individually to each battery in response to a measured charge condition of the specific battery. Thereby, the risk of a premature degradation of the batteries due to any imbalances in the state of charge (SOC) among the batteries may be reduced.

Hence, the prior art includes various examples of solutions for charging batteries which are advantageous with respect to different battery parameters, such as the cycle life (i.e. the number of times a battery may be recharged and discharged before it fails to meet a certain performance criterion).

However, there is yet no solution which significantly increases a battery's load capacity in respect of its usable SOC. Generally, if a voltage is fed to a battery which is equal to, or even below, the battery's nominal voltage, the battery will store an amount of energy which is less than its actual capacity. For example, a charging voltage equal to the nominal voltage may result in load capacity of 85% SOC for a standard lead-acid type of battery. By nominal voltage is here understood the output voltage which the battery is designed to deliver under normal operating conditions. Furthermore, no battery can drive a load with acceptable performance (i.e. relatively close to the nominal voltage) until it is fully discharged. Instead, the battery typically needs to be recharged when a 50%-SOC level has been reached. Consequently, if a standard battery is charged with a nominal voltage, its effective range of operation will be limited to an interval between 85% SOC and 50% SOC. Naturally, it is desirable to expand this interval and thus increase the battery's capacity.

One way to accomplish a broadening of the load-capacity

interval is to supply a charging voltage which exceeds the no-
minal voltage, and thereby increase the upper SOC. As a
general rule, the SOC increases with increasing charging
voltage. However, it is far from unproblematic to elevate the
5   charging voltage level. This may namely cause severe damage
to the units which are included in the electric system being fed
by the battery. For example, the service life of the light bulbs in
a typical vehicle system may be reduced with up to 50% for
each 0,5 Volt increase above the nominal voltage.

10   SUMMARY OF THE INVENTION
The object of the present invention is therefore to provide an
energy storage solution, which alleviates the problems above,
and thus offers an efficient charging without increasing the risk
of damaging any units that are included in the electric circuitry
15   to which the charged storage module is coupled.

According to one aspect of the invention, the object is achieved
by the arrangement for storing electrical energy as initially
described, wherein the DC-to-DC converter is adapted to control
each of the voltage fractions to vary over time within an interval
20   around a respective nominal module voltage.

An important advantage attained by this arrangement is that, for
each electrical storage module, the charging voltage may be
temporarily increased to a level which is sufficiently high to
obtain an improved load capacity (of, say 95% SOC). At the
25   same time, the overall voltage over the electrical storage
modules may be held at a nominal level, i.e. a harmless voltage
with respect to any units that are included in the relevant
electric circuitry.

According to one embodiment of this aspect of the invention, the
30   interval represents a voltage variation of less than 25% of any of
the nominal module voltages. This is namely sufficient to
accomplish a significant improvement of the load capacity for a

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majority of the electrical storage modules types currently on the market. It is also important that the interval is held relatively narrow because otherwise the voltage level may become too low to maintain an adequate SOC in the modules during those periods
5   when their voltage level is below the nominal value.

According to another embodiment of this aspect of the invention, the DC-to-DC converter is adapted to control the respective voltage fractions over the electrical storage modules, such that an average interval during which the voltage fraction exceeds
10   the nominal module voltage is substantially equal with respect to all the modules. This is desirable because thereby all the modules obtain an equally good load capacity (provided, of course, that they have essentially the same electrochemical characteristics).

15   According to yet another embodiment of this aspect of the invention, the DC-to-DC converter is adapted to control the respective voltage fractions over the electrical storage modules, such that in average, an equally large fraction of the DC-system voltage is distributed to each module. Again, this is preferable
20   from a load capacity point-of-view, at least if the modules have essentially the same electrochemical characteristics.

According to still another embodiment of this aspect of the invention, two or more of the electrical storage modules are included in a common battery unit. It is here presumed that a
25   separate set of access points is provided for each module, and that these access points are coupled to the DC-to-DC converter, such that the modules may be charged individually. This design is advantageous, since in some applications it may be appropriate to enclose all, or at least some, of the modules in one
30   battery unit, for example due for environmental reasons.

According to another embodiment of this aspect of the invention, the electrical storage modules are adapted to deliver energy to an electrical system of a vehicle via the first and second

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terminals. Naturally, this is desirable because in most vehicle applications, the storage modules will be required to deliver energy also during the normal charging procedure.

According to another aspect of the invention the object is achieved by a method of charging a number of electrical storage modules as initially described, wherein each of the voltage fractions is controlled to vary over time within an interval around a respective nominal module voltage. Thus, for each electrical storage module, the charging voltage may be temporarily increased to a level which is sufficiently high to obtain a significant improvement of the load capacity, without increasing the overall voltage to a level that may cause damages to any units that are included in the relevant electric circuitry.

According to one embodiment of this aspect of the invention, the interval represents a voltage variation of less than 25% of any of the nominal module voltages. As mentioned above, this is normally sufficient to improve the electrical storage modules' load capacity significantly in comparison with a standard nominal-voltage charging procedure.

According to another embodiment of this aspect of the invention, the respective voltage fractions over the electrical storage modules are controlled such that an average interval during which the voltage fraction exceeds the nominal module voltage is substantially equal with respect to all the modules. Namely, thereby all the modules obtain an equally good load capacity, at least if they have essentially the same electrochemical cha-racteristics.

According to another embodiment of this aspect of the invention, the respective voltage fractions over the electrical storage modules are controlled such that, in average, an equally large fraction of the DC-system voltage is distributed to each module. As stated above, this is preferable from a load capacity point-of-view if the modules have essentially the same electrochemical

characteristics.

According to a further aspect of the invention the object is achieved by a computer program directly loadable into the internal memory of a computer, comprising software for con-
5   trolling the above proposed method when said program is run on a computer.

According to another aspect of the invention the object is achieved by a computer readable medium, having a program recorded thereon, where the program is to make a computer
10   control the above proposed method.

Hence, the invention offers an excellent battery charging approach for any electrical system wherein a high load capacity is vital. The proposed solution is thereby particularly well suited for vehicle applications.

15   BRIEF DESCRIPTION OF THE DRAWINGS
The present invention is now to be explained more closely by means of embodiments, which are disclosed as examples, and with reference to the attached drawings.

Figure 1   shows a block diagram over an arrangement for
20   storing electrical energy according to a first em-
               bodiment of the invention,

Figure 2   shows graph for different charging voltages as
               functions of time according to the first embodiment
               of the invention,

25   Figures 3a-b show graphs specifically illustrating the charging
               voltages according to the first embodiment of the
               invention,

Figure 4   shows a block diagram over an arrangement for
               storing electrical energy according to a second em-
30   bodiment of the invention,

Figure 5   shows graph for different charging voltages as

functions of time according to the second
embodiment of the invention,

Figures 6a-c show graphs specifically illustrating the charging
voltages according to the second embodiment of
the invention, and

Figure 7   shows a flow diagram which illustrates the general
method according to the invention.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

A block diagram over an arrangement for storing electrical
energy according to a first embodiment of the invention is shown
in figure 1. The arrangement includes an electric charge source
110, such as a DC-generator, a DC-to-DC converter 120 and
first and second electrical storage modules 131 and 132
respectively, for example in the form of lead acid batteries.

The electric charge source 110 produces a DC-system voltage
V_{TOT} and is connected to a first and a second terminal T1 and
T2 respectively, such that the DC-system voltage V_{TOT} is applied
between the first terminal T1 and the second terminal T2.

The electrical storage modules 131 and 132 are connected in
series to one another with a first terminal polarity, e.g. negative,
of the first module 131 coupled to a second terminal polarity,
e.g. positive, of the second module 132. The first electrical
storage module 131 is also connected to the first terminal T1
with a second terminal polarity, e.g. positive, and correspon-
dingly, the second electrical storage module 132 is connected to
the second terminal T2 with a first terminal polarity, e.g.
negative. Thus, the DC-system voltage V_{TOT} is applied over the
electrical storage modules 131 and 132.

The DC-to-DC converter 120 is coupled to both the terminals T1
and T2, and to a point between the first and second modules
131 and 132 by means of an electrical connection 140. In

practice, this connection point may be identical to one of the module's 131 or 132 terminals. The DC-to-DC converter 120 receives incoming power from the electric charge source 110 via the terminals T1 and T2. The DC-to-DC converter 120 also delivers a voltage fraction V_1 and V_2 of the DC-system voltage V_{TOT} to each of the modules 131 and 132. By means of the electrical connection 140, the DC-to-DC converter 120 controls the voltage fractions V_1 and V_2, such that they vary over time. However the sum of V_1 and V_2 is always equal to the DC-system voltage V_{TOT}.

Figure 2 shows a first graph which illustrates how the voltage fractions V_1 and V_2 may be varied over time. The diagram's vertical axis indicates the DC-system voltage V_{TOT}, which here is assumed to remain essentially constant at a nominal level V_{TOTn}. Theoretically, however, the DC-system voltage V_{TOT} may vary, and in practice it often fluctuates to some degree, although a constant voltage value is generally desirable. The horizontal axis of the diagram indicates the time t.

A dashed line represents a first nominal voltage value V_{1n} for a first voltage fraction V_1 over the first electrical storage module 131. In this example, the first nominal voltage value V_{1n} is equal to $V_{TOT}/2$, however any other value is technically conceivable. Since the first nominal voltage value V_{1n} here is $V_{TOT}/2$, a second nominal voltage value V_{2n} for the second voltage fraction V_2 over the second electrical storage module 132 also becomes $V_{TOT}/2$.

The voltage fractions V_1 and V_2 are varied within an interval V_D around the respective nominal module voltage V_{1n} and V_{2n}. According to this embodiment of the invention, the voltage fractions V_1 and V_2 over the respective modules 131 and 132 vary over time t by periodically applying a voltage V_1 above the first nominal voltage value V_{1n} over the first module 131 while applying a voltage V_2 below the second nominal voltage value V_{2n} over the second module 132, and vice versa. Specifically, at

a first time instance t_1 a gradual decrease of the first voltage
fraction V_1 is initiated from an upper voltage level V_{1+}, and at a
second time instance t_2 a lower voltage level V_{1-} is reached. The
difference between the upper voltage level V_{1+}, and the lower

5   voltage level V_{1-} thus represents the interval V_D. Preferably, the
first nominal voltage value V_{1n} corresponds to the average value
of the upper voltage level V_{1+}, and the lower voltage level V_{1-}.
Figure 3a shows a graph which illustrates the specific variation
of the first voltage fraction V_1. At a third time instance t_3, a

10   gradual increase of the first voltage fraction V_1 is initiated, and
at a fourth time instance t_4, the upper voltage level V_{1+} is again
reached. At yet a later time fifth time instance t_5, the first
voltage fraction V_1 is lowered once more until the lower voltage
level V_{1-} is reached at a sixth time instance t_6, and so on.

15   Consequently, during a first interval τ_{super1} starting between the
third and fourth time instances t_3 and t_4, and ending between the
fifth and sixth time instances t_5 and t_6, the first voltage fraction
V_1 exceeds the first nominal module voltage V_{1n}. The charging
performed during this first interval τ_{super1} may thereby drive such

20   an amount of energy into the first electrical storage module 131
that it obtains a relatively good load capacity. If, for example,
the first nominal module voltage V_{1n} is 14 Volts, and the upper
voltage level V_{1+} is 15 Volts, a load capacity of 95% SOC may
be accomplished.

25   Figure 3b shows a graph which illustrates a corresponding varia-
tion of the second voltage fraction V_2. Here, a second interval
τ_{super2} during which the second voltage fraction V_2 exceeds the
second nominal module voltage V_{2n} starts between the first and
second time instances t_1 and t_2, and ends between the third and

30   fourth time instances t_3 and t_4. Thus, the charging performed
during the second interval τ_{super2} may drive such an amount of
energy into the second electrical storage module 132 that also
this module obtains a relatively good load capacity.

A variation of the voltage fractions V_1 and V_2 between 13 Volts

and 15 Volts as exemplified above, is equivalent to the interval V_D representing a voltage variation of $2/14 \approx 14\%$ of the nominal module voltages V_{1n} and V_{2n} (which are both 14 Volts). Such a variation is normally sufficient to ensure a first-rate load capacity

5   of the electrical storage modules. In any case, according to one embodiment of the invention, the interval V_D represents a voltage variation of less than 25% of any of the nominal module voltages V_{1n} and V_{2n}.

Moreover, the DC-to-DC converter controls the respective vol-

10   tage fractions V_1 and V_2 over the electrical storage modules 131 and 132 respectively, such that the first and second intervals τ_{super1} and τ_{super2} are approximately equal, at least on average. Thereby, both the modules 131 and 132 will have essentially the same load capacity (provided that their electrochemical charac-

15   teristics are essentially the same). Nevertheless, the length of the intervals during which the voltage fractions V_1 and V_2 are temporarily constant, (e.g. between t_2 and t_3; and between t_4 and t_5 respectively) is arbitrary and may be made infinitely short (i.e. $t_2 = t_3$ and $t_4 = t_5$), such that voltage fractions V_1 and V_2

20   vary continuously.

Although in many applications it may be desirable to control the respective voltage fractions V_1 and V_2, such that they voltage, on average, are substantially equally large, this is not necessary from a technical point of view. On the contrary, the nominal

25   voltage values may very well be individually different. Further- more, the super charging intervals (e.g. τ_{super1} and τ_{super2} above) may have different extensions in time.

Figure 4 shows a block diagram over an arrangement for storing electrical energy according to a second embodiment of the

30   invention, which elucidates these aspects of the invention. The arrangement includes an electric charge source 410, for example in the form of a DC-generator, a DC-to-DC converter 420 and first, second and third electrical storage modules 430A, 430B and 430C respectively, which may be lead acid batteries.

Also in this case, the electric charge source 410 produces a DC-system voltage V_{TOT} between a first terminal T1 and a second terminal T2. Moreover, the electrical storage modules 430A, 430B and 430C are all connected in series to one another with alternating terminal polarities. A first electrical storage module 430A is further connected to the first terminal T1 and a third electrical storage module 430C is connected to the second terminal T2. Thus, the DC-system voltage V_{TOT} is applied over all the electrical storage modules 430A, 430B and 430C.

The DC-to-DC converter 420 is electrically coupled to both the terminals T1 and T2, and to one point between each of the first, second and third modules 430A, 430B and 430C by means of respective electrical connections 441 and 442. The DC-to-DC converter 420 receives incoming power from the electric charge source 410 via the terminals T1 and T2. The DC-to-DC converter 420 also delivers a voltage fraction V_A, V_B, and V_C of the DC-system voltage V_{TOT} to each of the modules 430A, 430B and 430C. Via the electrical connections 441 and 442, the DC-to-DC converter 420 controls the voltage fractions V_A, V_B, and V_C, such that they vary over time. However the sum of V_A, V_B, and V_C is always equal to the DC-system voltage V_{TOT}.

Figure 5 shows graph (corresponding to the graph in figure 2) which illustrates how the voltage fractions V_A, V_B, and V_C may be varied over time. As is apparent from the figure 5, a first nominal voltage value V_{An} for the first voltage fraction V_A over the first electrical storage module 430A is lower than a second nominal voltage value V_{Bn} for the second voltage fraction V_B over the second electrical storage module 430B. The second nominal voltage value V_{Bn}, in turn, is lower than a third nominal voltage value V_{Cn} for the third voltage fraction V_C over the third electrical storage module 430C.

Also in this example, the DC-system voltage V_{TOT} is assumed to remain essentially constant at a nominal level V_{TOTn}, while the voltage fractions V_A, V_B, and V_C are varied over time t. All

variations, however, are held within an interval V_D around the respective nominal voltage value V_{An}, V_{Bn}, and V_{Cn}.

Figure 6a shows a graph which specifically illustrates how the first voltage fraction V_A is varied over time t. The DC-to-DC con-
5   verter 420 initially controls the first voltage fraction V_A to a first upper voltage level V_{A+} above the first nominal voltage value V_{An} during a first interval $t\Delta_1$. During a subsequent second interval $t\Delta_2$, the first voltage fraction V_A is controlled to the first nominal voltage value V_{An}, and during a following third interval $t\Delta_3$, the
10   first voltage fraction V_A is controlled to a first lower voltage level V_{A-} below the first nominal voltage value V_{An}. Then, during a fourth interval $t\Delta_4$, the first voltage fraction V_A is again controlled to the first nominal voltage value V_{An}. The fourth interval $t\Delta_4$, completes a full period, such that a subsequent fifth interval $t\Delta_5$
15   is equivalent to the first interval $t\Delta_1$.

Figure 6b shows a corresponding graph specifically illustrating how the second voltage fraction V_B is varied over time t. The DC-to-DC converter 420 here controls the second voltage fraction V_B to, during the first and the second intervals $t\Delta_1$ and
20   $t\Delta_2$, attain a voltage value which is given by a second lower voltage level V_{B-} below the second nominal voltage value V_{Bn}. Then, during the third and the fourth intervals $t\Delta_3$ and $t\Delta_4$, the second voltage fraction V_B is controlled to a voltage value represented by a second upper voltage level V_{B+} above the
25   second nominal voltage value V_{Bn}. A following fifth interval $t\Delta_5$ is equivalent to the first interval $t\Delta_1$.

Finally, figure 6c shows a graph which specifically illustrates how, in this example, the third voltage fraction V_C is varied over time t. During the first interval $t\Delta_1$, the third voltage fraction V_C
30   is controlled to the third nominal voltage value V_{Cn}, and during the second interval $t\Delta_2$ it is controlled to attain a voltage value given by a third upper voltage level V_{C+} above the third nominal voltage value V_{Cn}. Subsequently, during the third interval $t\Delta_3$, the third voltage fraction V_C is again controlled to the third

nominal voltage value V_{Cn}, and during the fourth interval $t\Delta_4$, the third voltage fraction V_C is controlled to a voltage value at a third lower voltage level V_{C-} below the third nominal voltage value V_{Cn}. In analogy with the above, these four intervals $t\Delta_1$-$t\Delta_4$

5   completes a full period, such that a following fifth interval $t\Delta_5$ is equivalent to the first interval $t\Delta_1$.

Thus, both the first voltage fraction V_A and the third voltage fraction V_C are varied over time t, such that they periodically attain their respective nominal voltage values V_{An} and V_{Cn},

10   namely during every second interval. The second voltage fraction V_B, however, is controlled such that it never attains its nominal voltage value V_{Bn}. It is nevertheless worth noticing that the DC-to-DC converter 420 controls all the voltage fractions V_A, V_B and V_C to vary within the interval V_D around their respective

15   nominal voltage value V_{An}, V_{Bn} and V_{Cn}. According to one embodiment of the invention, the interval V_D represents a voltage variation of less than 25% of any of the nominal module voltages V_{An}, V_{Bn} and V_{Cn}.

In order to sum up, the general method of charging a number of

20   electrical storage modules according to the invention will now be described with reference to a flow diagram in figure 7.

A first step 710 receives the DC-system voltage, for example between a first and a second terminal. A subsequent step 720, converts the DC-system voltage into one voltage fraction per

25   module. The step 720 also varies each voltage fraction over time within an interval around the respective nominal module voltage. Finally, a step 730 delivers the relevant voltage fractions to each of the modules.

Naturally, the steps 710, 720 and 730 are actually performed

30   continuously and in pseudo-parallel to each other, such that a DC-system voltage received in the step 710 essentially immediately is delivered to the electrical storage modules via the step 730.

All of the process steps, as well as any sub-sequence of steps, described with reference to the figure 7 above may be controlled by means of a programmed computer apparatus. Moreover, although the embodiments of the invention described above with reference to the drawings comprise computer apparatus and processes performed in computer apparatus, the invention thus also extends to computer programs, particularly computer programs on or in a carrier, adapted for putting the invention into practice. The program may be in the form of source code, object code, a code intermediate source and object code such as in partially compiled form, or in any other form suitable for use in the implementation of the process according to the invention. The carrier may be any entity or device capable of carrying the program. For example, the carrier may comprise a storage medium, such as a ROM (Read Only Memory), for example a CD (Compact Disc) or a semiconductor ROM, or a magnetic recording medium, for example a floppy disc or hard disc. Further, the carrier may be a transmissible carrier such as an electrical or optical signal which may be conveyed via electrical or optical cable or by radio or by other means. When the program is embodied in a signal which may be conveyed directly by a cable or other device or means, the carrier may be constituted by such cable or device or means. Alternatively, the carrier may be an integrated circuit in which the program is embedded, the integrated circuit being adapted for performing, or for use in the performance of, the relevant processes.

The term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components. However, the term does not preclude the presence or addition of one or more additional features, integers, steps or components or groups thereof.

The invention is not restricted to the described embodiments in the figures, but may be varied freely within the scope of the claims.